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Radio-Astronomical Experiments in the 70cm Band

At the 1990 VHF-UHF Congress, Hermann Hagn - DK8CL - presented the first results obtained from his amateur radio telescope using a 3m mirror. The following article demonstrates how, by using a different signal processing technique, you yourself can detect cosmic radio emissions using a single 19-element Yagi.

1. SELECTING THE OBSERVA- TION FREQUENCY

The stimulus to getting involved in radio-astronomical experiments came from DK8CL's paper at VHF-UHF 90 (1), which investigated cosmic radio emissions in the frequency range around 1.72 GHz. Since not every

amateur has a fully mobile 3m mirror, the obvious question was whether you couldn't also work with simpler Yagi aeriels. With this in view, the first matter to be clarified is the optimal observation frequency.

In the present state of receiver technology, extremely low noise factors can be easily attained, even in the gigaHertz range, so that no clue can be derived from this. In the end, the thermal noise from the receiver installation is caused by the "black body radiation" which all warm bodies transmit, and the spectrum distribution of which is described by Planck's law of radiation.

In the high-frequency and microwave ranges, we describe the noise properties of an amplifier in terms of the noise temperature. The noise output of an ohmic resistance is described using the known equation:

$$Pr = kT_0B$$

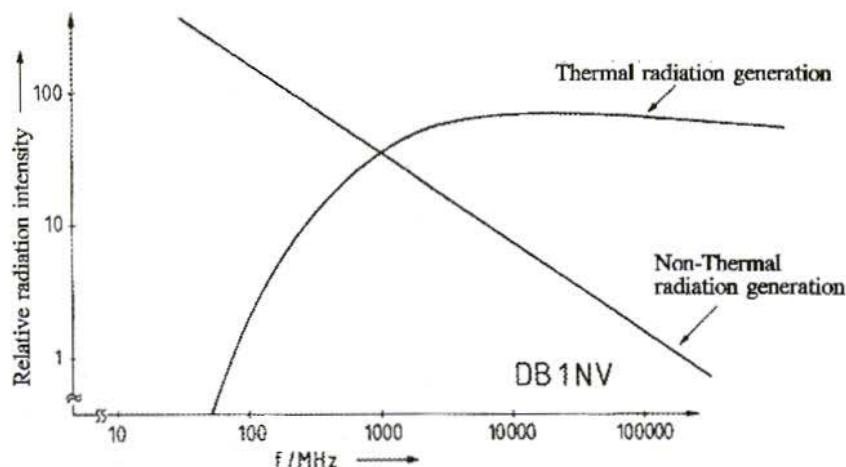


Fig.1: Radiation Properties of Astronomical Objects in the Microwave Range

where

$k = 1.38 \times 10^{-23} \text{Ws/K}$ Boltzmann constant

$T_0 =$ Absolute temperature in degrees Kelvin

$B =$ Signal bandwidth in Hertz

This is also known as the Johnson approximation. Here the noise output is independent of the frequency and is conditioned only by the temperature and the band width. The noise temperature of an amplifier is the temperature of a moving load at the input, at which the amplifier noise is equal to the resistance noise. Even a few astronomical objects, such as the Sun and the Moon, emit predominantly thermal radiation, corresponding to their surface temperature. Depending on the optical density of the object, we receive noise output densities which are either constant or rising with the frequency.

Anyone wanting to know more about thermal radiation and how it can be

described mathematically will find further information in (2) and (3). Most radio-astronomical sources also generate radiation through non-thermal processes, such as synchrotron radiation from electrons moved in the magnetic field. Non-thermal radiation is characterised by a power density which decreases as the frequency increases, in accordance with (4). Fig.1 from (4) gives a much simplified picture of the spectrum distribution of thermal and non-thermal radiation sources.

Apart from the Sun, the most powerful radio sources are mainly of non-thermal origin. So it seems sensible to choose a low observation frequency for our first experiments. The lower limit will be determined by the dimensions of the aerial and the level of interference from the atmosphere, domestic appliances and industry, which increases below 1 GHz. Even professionals sometimes accidentally include home-made interference signals in their measure-

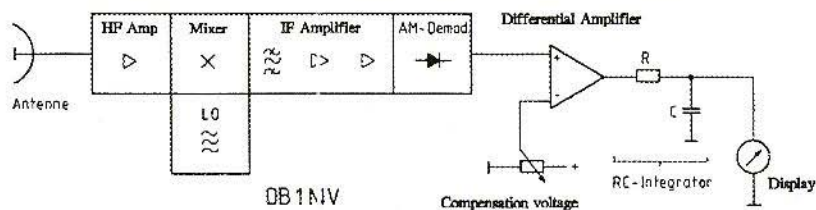


Fig.2: A Radio-Astronomical Direct Receiver

ments, and many "pulsars" have turned out to have their origins in an electric fence in a nearby pasture.

So the author decided to carry out his experiments in the 70cm band. This frequency is not far from a standard radio-astronomical observation band (406 - 410 MHz).

2. RECEIVER TECHNOLOGY

The simplest radio-astronomical receiver, which is also the type used in (1), is shown in outline in Fig.2. After multiple amplification and frequency conversion, the input signal reaches a rectifier which demodulates the noise signal. The output voltage contains a large fraction stemming from the residual noise of the receiver installation and a small, variable fraction from the radio source in space. So we subtract an adjustable DC voltage, which corresponds to the receiver noise

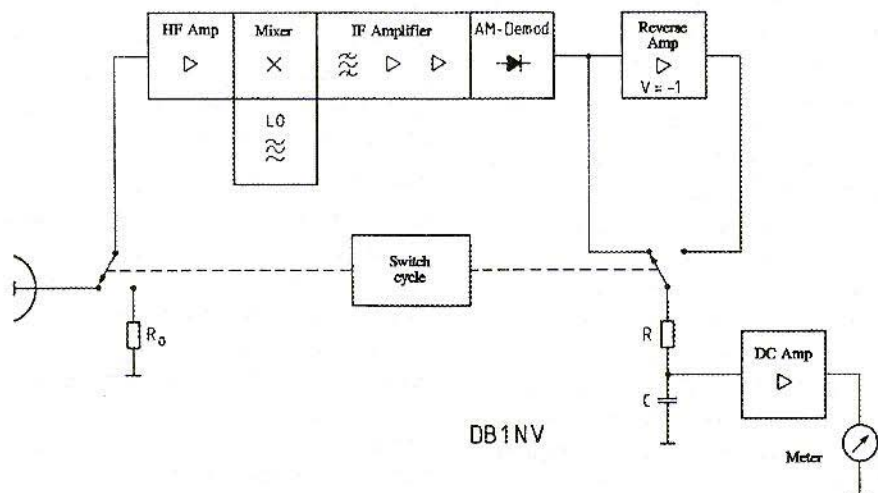


Fig.3: A Radio-Astronomical Receiver as per the Compensation Principle (Dickie Receiver)

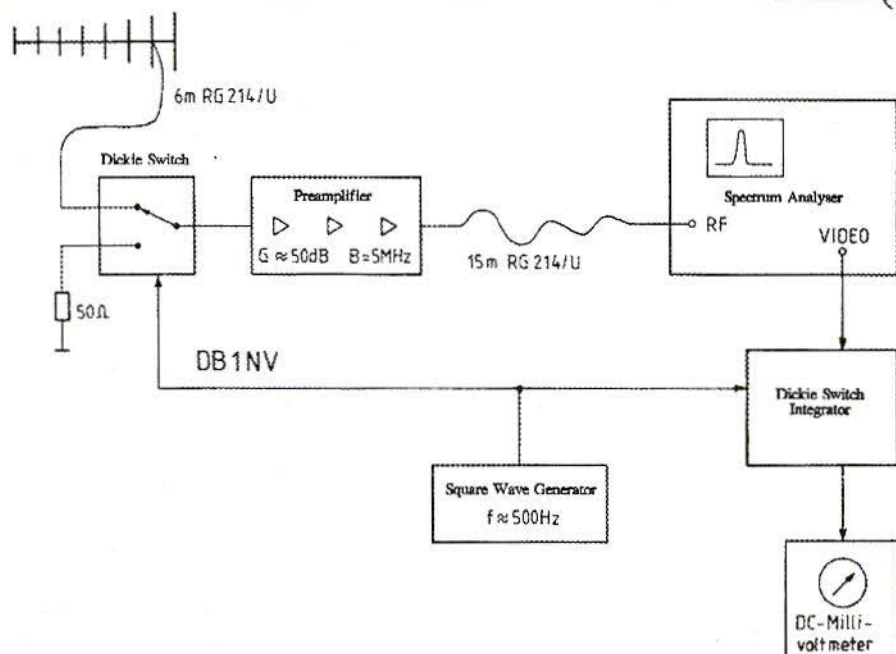


Fig.4: The Author's Dickie Receiver

and greatly increases the difference. An RC module with a long time constant in the seconds range provides information on the static oscillations of the noise level, and the smoothed voltage controls the display instrument or the recorder.

The disadvantages of this layout are obvious. If the noise reading of the receiver or its amplification oscillates to only a minimal extent, then this immediately shows through in the output as zero point drift.

Since these problems were actually much more serious in the valve era, the radio-astronomer Robert Dicke, of the Massachusetts Institute of Technology, developed a solution in 1946, which is still called a "Dicke receiver" today. Fig.3 shows the outline layout. At the

input of the receiver is mounted a switch, which periodically connects the receiver with the aerial or with a terminating load. At the receiver output is a second, synchronously operating switch, which continuously switches the inverted output voltage to the output-side low pass filter when the receiver is connected to the terminating load.

Thus the receiver noise is periodically subtracted from the total signal. As can easily be comprehended, a (slow) change in the receiver noise factor has essentially no effect on the measurement, and an amplification drift influences only the size of the reading, not the zero point.

A professional Dicke receiver can still detect signals which are 30dB below the noise!

3. A SIMPLE DICKE RECEIVER

Fig.4 shows the author's 70cm band experimental rig: a single 19-element Yagi (!) with app. 15dB gain powers the Dicke switch through 6m of RG214/U. Naturally, it would have been more advantageous to mount the switch and the pre-amplifier directly on the aerial and not in the attic, and thus eliminate the 1.5dB cable damping, but in the development phase it's more important to have an accessible installation location.

The pre-amplifier is a five-stage former channel amplifier for television band IV, which was balanced at 435 MHz. Its first stage had been equipped with a CF300 to bring the noise factor down to values below 1dB. The Philips amplifier used, with high-quality, cleanly dimensioned, silver-plated shell circuits, was most suitable for this application.

It is important here that the pre-amplifier should not oscillate, even in the case of a false adapted load at the moment when the switch is switched, since the high-frequency pulses which otherwise arise are controlled by the receiver downstream. The CF300 drain circuit thus has 100 Ω damping and is only loosely coupled to the next circuit. The pre-amplifier has a band width of 5 MHz and an amplification of about 50dB.

The receiver used was the author's spectrum analyser, which is operated in zero span mode. Switching to analyser

mode enables interference signals to be located rapidly. The second part of the Dicke switch is connected to the video output of the analyser and powers the display instrument, an analogue millivoltmeter. The switch cycle originates from a square-wave generator, e.g. a function generator.

As can be seen, the receiver uses standard technology for the most part. So it's only the unusual Dicke switch assemblies which require closer examination.

Fig.5 shows the high-frequency switch, which consists of two PIN diodes (type BA379 or BA479), which are controlled alternately by a zero-symmetrical AC voltage of about 10 V_{ss}. The diode which is blocked at any time certainly sees only 0.7 V "blocking voltage" - namely the flow voltage of the conducting diode. But no interference arises through capacitive inductive disturbance.

It is important that the downstream pre-amplifier has a high pass filter at the input, since otherwise harmonics from the switching frequency modulate the operating point in such a way as to cause interference.

The output side part of the Dicke switch is an operational amplifier, which can be wired up to the +1/-1 amplification using a FET (5). The low pass filter after the switch has a limiting frequency of 1 Hz, so that the display function is not too sluggish if the aerial is manually set. The output-side pre-voltage potentiometer can be used to balance the display at zero if there is no signal (Fig.6).

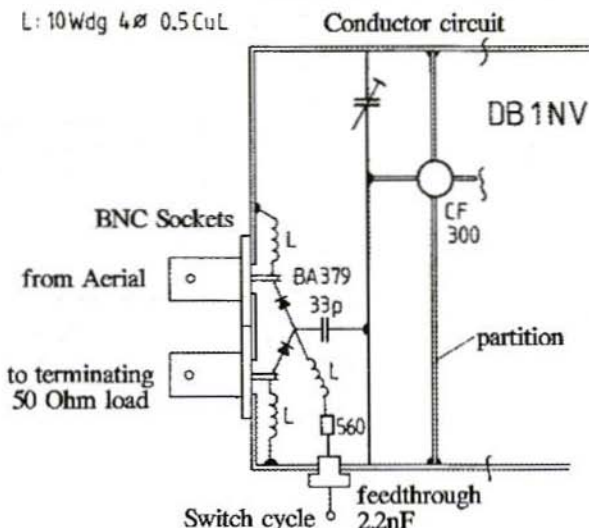


Fig.5:
The High-Frequency
Switch at the
Preamplifier Input

4.

RESULTS OF OBSERVATION

In the first experiment, the solar noise was investigated without a Dicke switch. On various days, an increase in noise of between 3 and 4dB was detected. The variations can clearly be traced to varying environmental interference levels. The solar noise was then used to optimise the Dicke switch. The steadiest display was obtained using the maximum intermediate-frequency band width of the analyser (200 kHz), a 500 Hz switch cycle, and a video band width of 1 kHz. The switch cycle turned out to be relatively uncritical. The thermal noise from the warm ground can be satisfactorily detected by the measuring rig if the aerial is swung up from 0° elevation.

Anyone reconstructing these results will straight away find a number of "sus-

pect" signals, all of which are of earthly origin. It is only at night or at the weekend that the author can carry out reasonable observations in a residential area. The daytime interference level during the week is far too high. Many weak little carriers can be detected in the evening, and these are probably interference signals from television sets in the form of cycle harmonics. As these are narrow-band interference sources, you can usually find a free segment of the band where there is no interference.

Atmospheric inversion conditions with overshoots are unsuitable for observations, since at such times the entire 70cm band is occupied by weak signals. In case of doubt, the only thing that helps is to observe a signal for several hours, to see whether the source moves as the Earth rotates (15° an hour).

So far the following objects have been observed (in late Summer and Autumn):

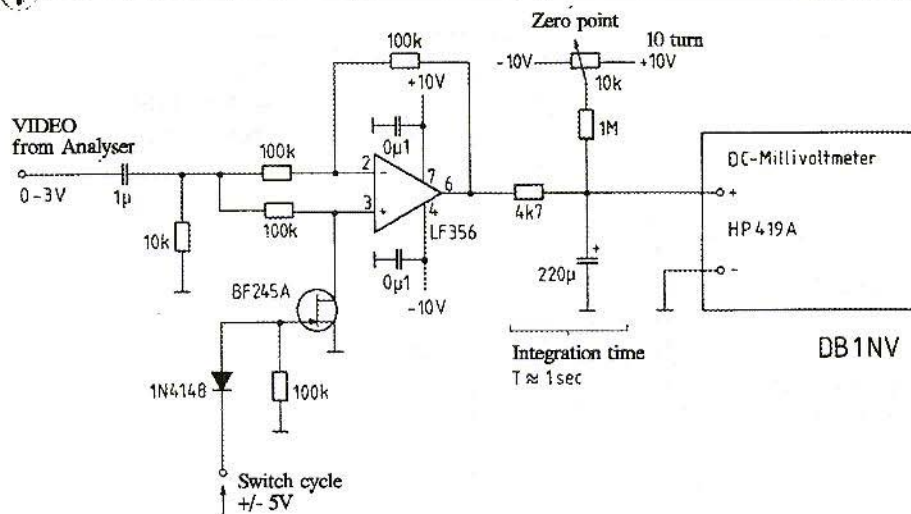


Fig.6: The Output-side Switch

The strongest source, apart from the Sun, is the galactic centre in the constellation of Sagittarius. The maximum reading was obtained in the South at 20° elevation, towards 9.00 p.m. Summer Time, at the end of August. Even at 0° elevation, the signal clearly rose above the thermal Earth noise.

A very weak signal could be found at the same observation time from an Easterly direction at 70° elevation. It was about 14dB below the Earth noise. It was possibly the Cygnus A source in the Cygnus constellation.

At about 10.30 p.m. one evening at the end of August, another very weak source was found below 20° elevation in the Northeast. It could be assigned to the Cassiopeia A source.

A search for the thermal signal from the Moon and for emissions from the Crab

Nebula in Stier during January and February was unsuccessful. At the time of the search, the interference level in the 70cm band was definitely high. At 100 MHz, the Crab Nebula is weaker by a factor of 10 than the strongest sources Cassiopeia and Cygnus.

Following these encouraging results, obtained using the simplest of aerial installations, the author is planning to repeat the experiment with Yagis dimensioned for 408 MHz and with a Dicke switch/pre-amplifier mounted directly at the distributing point.

In the 406 - 410 MHz reserved for radio astronomy, a low interference level should be reckoned with. Moreover, a change in the QRL should offer the possibility of using a professional two-axis rotating stand for the experiments.



5.

APPENDIX: ESTIMATING THE SENSITIVITY OF THE RECEIVER SYSTEM

According to the manufacturer, the 19-element aerial used has a gain of 15dB over a dipole, which corresponds to an aerial gain of 32. With a dipole absorption area of

$$A_D = 0.13\lambda^2 = 6.37 \cdot 10^{-2} \text{m}^2$$

we have a Yagi aerial absorption area of:

$$A_y = G \cdot A_D = 32A_D = 2\text{m}^2$$

According to (6), the radio source Cassiopeia A supplies a power flow of $S = 18600 \cdot 10^{-26} \text{ W/m}^2\text{Hz}$ at 100 MHz. It can be estimated from (4) that the non-thermal radiation output of a radio source falls by 6.7dB per decade when the frequency rises. Consequently, it is 4dB smaller at 430 MHz than at 100 MHz, and amounts to $S_{430} = 7400 \cdot 10^{-26} \text{ W/m}^2\text{Hz}$. For a receiver band width of 200 kHz, the receiver aerial supplies a signal of:

$$\begin{aligned} P_S &= S_{430} \cdot B \cdot A_y \\ &= 7400 \cdot 10^{-26} \frac{\text{W}}{\text{m}^2 \cdot \text{Hz}} \cdot 2\text{m}^2 \cdot 2 \cdot 10^5 \text{ Hz} \\ &= 3 \cdot 10^{-17} \text{W} = -135\text{dBm} \end{aligned}$$

If the system noise temperature is assumed to be $T = 500 \text{ K}$, which is credible on the basis of the cable losses between the pre-amplifier and the aerial, then the noise output of the receiver installation amounts to

$$P_R = kT_0B = 1.38 \cdot 10^{-23} (\text{Ws/K}) \cdot 500\text{K} \cdot 2 \cdot 10^5 (1/\text{S})$$

$$= 1.4 \cdot 10^{-15} \text{ W} = -118\text{dBm}$$

Consequently, the radio-astronomical signal is about 17dB below the thermal noise.

The simple Dicke receiver is clearly able to detect signals which are 17dB below the inherent noise of the receiver. Professional receivers attain values above 30dB here.

6.

LITERATURE

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